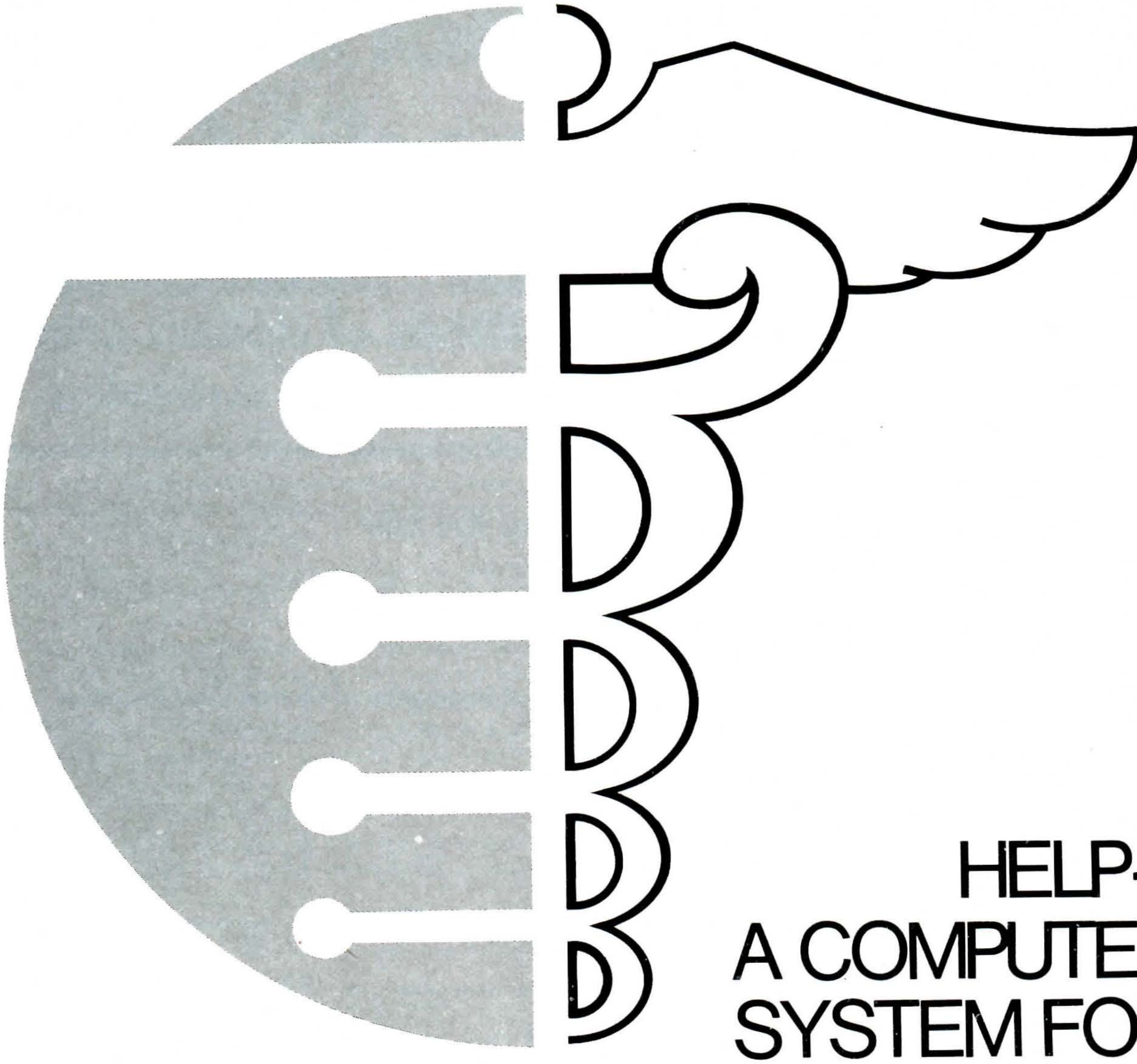

HELP— A COMPUTER SYSTEM FOR MEDICAL DECISION MAKING

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Introduction

The medical record is maintained for the express purpose of enabling the physician to deliver better care to the patient. But its usefulness in achieving that purpose has often been hampered by its inflation with voluminous, unorganized notes, and test results. The medical profession has begun to recognize this, and work has recently been done in reviewing the structure of the medical record with hopes of making improvements.[1] Based on what has been learned so far, it appears that the most effective record is one containing a broad data base including many investigative procedures, while at the same time focusing the physician's attention on problems or diagnoses derived from the data base.[2] These problems express only the essential information derived from the data base—that information which forms the basis for the treatment regimen.

This paper presents a computerized system for coding and extraction of higher-order medical information (e.g., findings, problems, and diagnoses) from an extensive medical base.[3]

HELP—A System for *H*ealth *E*valuation through *L*ogical *P*rocessing

The HELP system was developed on the computer facility at the Latter-Day Saints Hospital in Salt Lake City, Utah. This facility includes two Control Data (CDC) 3300 Computers, each with 65K of core memory.[4] One of the computers is designated as the research system where all new program development is undertaken. The other computer is designated the clinical system where all of the clinical services are provided to the hospital. Users interact with the system through video terminals. Program development and execution are allowed from these terminals. At present there are about 40 terminals connected to the clinical system and 20 terminals connected to the research system. Both research and clinical systems access the HELP programs and patient data files through common disk drives (3 CDC 841 disk drives and 7 CDC 854 disk drives). Additional peripherals on the system include printers, magnetic tapes, card reader, analog to digital converters, digital to analog converters, etc.

The design criteria used in developing the HELP system are as follows: (1) Data should be acquired insofar as possible by direct input into the computer from automated equipment (e.g., electrocardiogram, spirometry, clinical laboratory data, etc.). However, data can also be entered in HELP via physicians, paramedical intermediaries, and by the patient himself.[5] (2) HELP should isolate the physician from the direct collection of data, permitting him to concentrate more of his efforts on the evaluation of the computer-defined problem statements. The fact that most of the data is collected from extra-physician sources does not preclude the entry of problems and data, or the modification of problem statements by physicians. (3) The medical logic developed for HELP should be in a form which is readily transferable to other physicians and other computer systems. (4) Finally, the computer response time of HELP must be such that excessive delays (greater than 10 seconds) will be the exception.

By using the computer to define problems, a number of advantages are realized: (1) the physician handles a much smaller volume of data than if he were making all decisions and entries in the medical record himself. (2) The expert physician's logic is accessible to the non-expert on a 24-hour basis. (3) The problems and diagnoses generated become standardized.

System Organization and Functions

To accomplish the decisionmaking task, three files have been generated: the patient data file, the decision criteria file, and the problem file. The patient file has a capacity of 2048 patients. The Latter-Day Saints Hospital is only a 550-bed hospital, but since a patient cannot be discharged from the system until his record is completed with the addition of a discharge summary, the file generally contains between 1000 and 1500 patient records. This file contains data from the admission screening laboratory, the clinical chemistry laboratories, pulmonary function laboratory including blood gas data, the heart catheterization laboratory, the intensive care units, the pharmacy, medical records, and electrocardiograms (ECG) from the heart station. Some of the sources are automated—e.g., the ECG and spirogram—whereas others, such as medical records, require a paramedic or the patient to interact. All data on which decisions are to be made are stored in numeric or coded form (i.e., no decisions are in free text English entries). Since most decisions regarding findings are made from data from a single data field or from a few related data fields, subfiles arranged by field class are created in the patient data file.

The decision criteria file contains the decision logic, stored on disk sectors, by which the patient data is analyzed to define the problem. The structure of this file—at least from the user's point of view—follows the rational syntax used by the physician in the description of problem criteria.

Finally, a problem-oriented record (POR) is created for each patient. The creation of this file is the ultimate goal of HELP. Problems defined in this file are used in planning the care of the patient, in reporting the condition of the patient, and in review of patient care. This file is, therefore, a problem abstract of the patient record. Information in the POR includes physician review and acceptance of the problem (whether or not the problem is now current) and the problem level. The problem level is used to indicate a hierarchy of problems (i.e., is this problem intermediate to some higher level problem?) Each patient's POR is available to the physician as a hardcopy report or on terminals.

Figure 1 shows an example of how HELP is used. Consider in this example the generation of an ECG diagnosis. First, the ECG is sampled by the computer. Next, parameters relating to the ECG morphology and rhythm are extracted and placed in the patient data file. HELP is then called to process the data for the ECG data field—i.e., the file containing criteria pertinent to the evaluation of the ECG are read from the criteria file and processed using the patient's ECG data file. The resulting ECG diagnosis is then placed in the POR from which a report is printed.

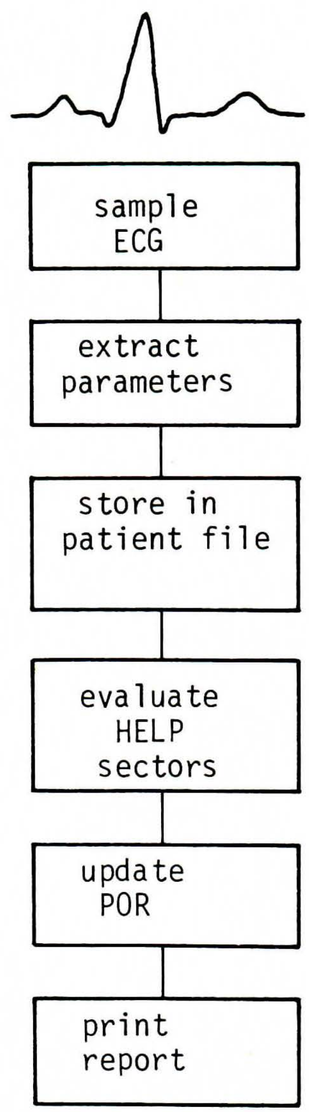

Figure 1. Block diagram of steps involved in generation of a HELP decision from electrocardiographic data.

It is also possible to make a decision involving information from other data classes. For example, an ECG finding of "ischemic pattern" (an ECG abnormality generally associated with a lack of oxygen to some portion of the heart muscle) may have resulted from the last ECG, and this pattern in conjunction with a history finding of angina (chest pain) and a laboratory finding of elevated creatine phosphokinase (CPK)—an enzyme measured in the blood—can be used to establish a diagnosis of myocardial infarction (heart attack). An ECG decision sector could, therefore, make this diagnosis by evaluating the ECG data and then request a search of the POR to determine if the relevant history findings and the presence of elevated CPK were present on the patient. For these circumstances, a diagnosis of "myocardial infarction" (i.e., occlusion of the blood supply to some portion of the heart) would be made.

To generate a decision sector, an investigator calls the decision generation program from a computer terminal. He first specifies the problem class (e.g., ECG, blood gas, etc.) on which he is working. If that class is not already defined in HELP, he defines a new class and begins generating decision sectors for the class. If, however, the class is an existing one, the decision sectors for that class are transferred to an area on disk where he may now modify or create sectors for the class without jeopardizing any decisions being made from that class during the time that modifications are being made.

To create a new decision sector, the type of sector must be defined. Two types are presently used. The first are boolean sectors—i.e., the evaluation of these sectors will be from a boolean logic statement that is evaluated as either true or false. Such a sector could be one to diagnose hypertension, whereupon the evaluation of the boolean statement for that sector would indicate the presence or absence of hypertension. The second type of sectors is arithmetic sectors. Evaluation of these sectors is from an algebraic statement resulting in a numeric value being generated for the sector. For example, a sector to measure the probability of hypertension wherein the outcome of the evaluation of the sector is the probability of the patient having hypertension.

A message may be associated with the sector. In the case of arithmetic sectors, the message will contain a series of equal signs which are replaced by the value of the sector when the message is displayed. For boolean sectors, a message corresponding to the decision is entered. The length of the message is variable and can contain up to 640 characters. These messages are not stored as a part of the decision sector, but are stored in a separate message file. If no message is associated with the sector, the investigator proceeds to the next step of sector generation, i.e., generation of the decision logic.

This step corresponds to the writing of a series of statements which will define the necessary logic associated with the sector. Since in all decisions it will be necessary to extract data from the patient's data file, several options are available to search through the patient's data file for location of specified information. The possible data which can be searched include (1) the results of another sector within the same class, (2) problems contained in the POR, and (3) patient data.

Another type of statement allows the user to write an arithmetic or boolean expression. This expression is written as a Fortran-type statement and references the information of the search statements. Modifiers for the data search statements may be added. If none are added, it is assumed that the last occurrence of that variable in the patient file is the one desired. The list of possible modifiers includes first occurrence, last occurrence, maximum value, minimum value, average, median, mode, frequency of occurrence, and trend. Time constraints for the search may also be specified. These time constraints specify a constraint relative to the present time or relative to the occurrence of a particular search statement. An example of the search for a piece of data might be "the average heart rate over the last four hours."

After generation of the statements the investigator enters a final decision statement for the sector. The restrictions on the statement are the same as those on other statements. Clearly, if the sector is boolean the statement will be boolean, and if the sector is arithmetic the statement will be arithmetic.

Figure 2 is an example of a typical HELP sector. In this figure we see that the decision which is to be made is from the heart catheterization laboratory and is that of moderate tricuspid (referring to a valve between the chambers of the right heart) stenosis. The final evaluation statement to be processed is true if statement H is true and statement B

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          SECTOR      8
MODERATE TRICUSPID-STENOSIS
    H AND (B GE 18) AND ( NOT F OR G)
A  DEG. DIAST. PRESS. R.V.  REST  MEDN ANY TIME
B  MEAN PRESS.        R.A.  REST  MEDN ANY TIME
C  DIAST. GRAD.  R.A.-R.V.  REST  MEDN ANY TIME
D  DEG. DIAST. PRESS. R.V.  O2    MEDN ANY TIME
E  MEAN PRESS.        R.A.  O2    MEDN ANY TIME
F  SEVERE TRICUSPID STENOSIS
G      C LT 14
H      (B-A GE 17) OR (C GE 14) OR (E-D GE 17)
CHANGE MESSAGE(1), FINAL EVALUATION(2), SECTOR LOGIC(3), NEW SECTOR(4),
OTHER OPTIONS(5)_
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Figure 2. Example of a HELP decision sector to diagnose moderate triscupid stenosis.

(mean right atrial pressure) is greater than 18 mm Hg and either statement F is false or statement G is true. Statement A, in this example, indicates a search for the median beginning diastolic pressure of the right ventricle at rest. No time constraints are given. This value is then used as a part of boolean statement H where it is subtracted from the mean pressure of the right atrium. Note that statement F, severe tricuspid stenosis, refers to another decision sector within the heart catheterization class whose value would be either true or false.

The order of decisionmaking to be followed by HELP is also specified by the investigator—that is, the order in which the sectors should be processed at decision time. The reason for this feature rises from the mechanism of sector evaluation by HELP. HELP has been designed to minimize the number of disk accesses required to make a decision. This is accomplished by sequentially storing the decision sectors of one class in such an order that the next sector in the sequence can always be evaluated without further disk accesses. This is made possible by storing the sectors on disk in such an order that all within-class sectors referenced by a given sector are sequenced on disk prior to the sector being evaluated. Thus, its results are available to the sector under consideration.

This sequencing is accomplished by the program when the investigator returns the sectors for use in the system. If the investigator has requested a decision order, HELP generates a "stack" of sectors having a minimum path length to the first decision sector specified by the user. If, for example, the user has requested that sector 2 be the first decision made, followed next by sector 5, HELP will search through the statements of sector 2 looking for references to other sectors. If any are present, these sectors are searched looking for additional references. This is continued until only sectors without references to other sectors are encountered. Using this information a sector "stack" is created with the requested sector at the top of the stack. The sectors are now ordered in the desired sequence and can be written to the appropriate disk area. In such an example, even though sector 2 was requested before sector 5, the natural ordering of the system may require that sector 5 be evaluated first if it were referenced by one of the sectors. Another feature which aids in minimizing computation time is designation of sectors as class terminators. Designation of a sector as such will cause the HELP evaluation program to end processing of sectors for that class if the value of the terminator sector is true. For example, in the case of ECG's the classification of a normal ECG would suspend evaluation of other impossible results.

Figure 3 is a flow diagram of the on-line decision process. As seen in this figure, a field of data is acquired by the system. This data is stored in the patient's file, and then HELP calls a program which accesses the list of sectors pertinent to this data type. If the list is null, the system returns and no decision is made. Otherwise, those sectors are processed and the POR updated. If a problem is set in the POR the process is iterative. That is, the new problem which has now been set in the patient's POR becomes a new data field and is used to access a new list of sectors. This process is continued until either the appropriate lists are null or no new additional problem is set in the POR.

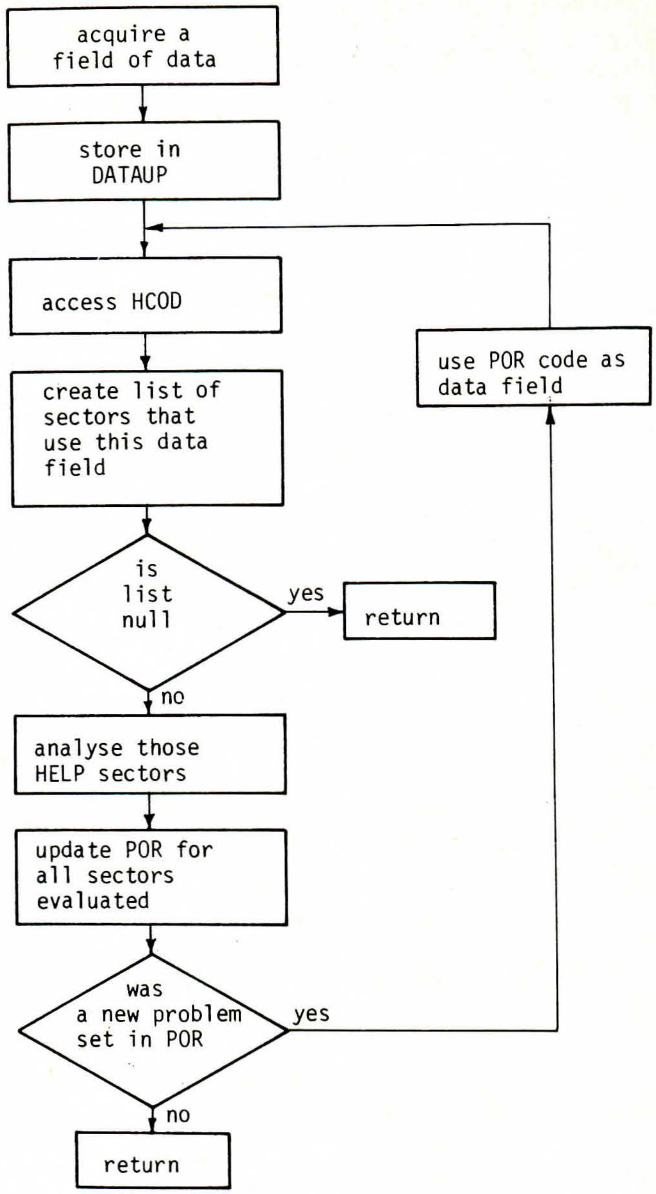

Figure 3. Flow diagram of logic steps involved in on-line HELP decision process.

Conclusion

The HELP system has been operational in the Latter-Day Saints Hospital for more than two years. All of the features of HELP outlined in this paper are now operational. However, experience with the system has shown that additional features must be included before realization of all the design criteria can be achieved. Because of the frequent upgrading of the HELP system, programs are still not core resident and must be retrieved from disk. Therefore, some response times of 30-40 seconds during peak hours of system utilization have been noted. As the system becomes integrated into our operating system we expect a significant improvement in this time.

As for the other design criteria, the first was satisfied by virtue of the fact that the original computer system around which the HELP system was developed was one of automated data collection and reporting. The second criterion will require more evaluation as more services are incorporated in the system. Although the medical logic can be easily communicated to other physicians we feel it is necessary to develop a minicomputer version of HELP before it will be readily transferred to other computers. Development of such a mini-system is now being explored.

The major uses of the system have been in blood gas interpretations, pulmonary function analysis, ECG interpretation, and analysis of heart catheterization data. Decisions in these areas normally require about 200 inquiries per day. New decision sectors are now being generated with the cooperation of several physician consultants. These new areas include drug interaction logic, coronary care logic, and interpretation of specific outpatient protocols (e.g., control of diabetes). Frequent interaction with the consultants is necessary in these new areas to converge on precise logic in the criteria file.

Although this paper has stressed the POR-generating capability of this system, this criteria file can be used for several purposes. It may be used first in the mode that has been described in this paper—i.e., for consultation by those aiding in patient care. A second use of the system would be evaluation of patient care—i.e., sectors would be developed with criteria for peer review. For example, logic could be generated which might specify that for a particular surgical procedure certain laboratory tests should be administered. Thus, a search of a patient's data could determine whether or not those tests had been given to that patient. A third mode of the system is the teaching mode wherein medical students would both be shown the decision logic determined by experts and be tested by simulating a particular patient condition in order to compare their decisionmaking process to that of the experts. Finally, with the data base and the files generated, the system becomes an effective tool for clinical research. It is our opinion that such a system will provide a mechanism for generation of new standards of medical care.

References

1. Alvan R. Feinstein, "The Problems of the 'Problem-Oriented Medical Record,'" *Annals of Internal Medicine,* Vol. 78, pp. 751-762, 1973.

2. L. L. Weed, *Medical Records, Medical Education, and Patient Care: The Problem-Oriented Record as a Basic Tool,* Case Western Reserve University Press, Cleveland, Ohio, 1969.

3. Homer R. Warner, Charles M. Olmsted, and Barry D. Rutherford, "HELP—A Program for Medical Decision-Making," *Computers and Biomedical Research,* Vol. 5, pp. 65-74, 1972.

4. T. Allan Pryor, Reed M. Gardner, and W. Clinton Day, "Computer System for Research and Clinical Application to Medicine," *AFIPS Conference Proceedings,* Vol. 33, pp. 809-816, 1968.

5. Homer R. Warner and John D. Morgan, "High-Density Medical Data Management by Computer," *Computers and Biomedical Research,* Vol. 3, pp. 464-476, 1970.

Acknowledgment

Supported in part by a Health Resources Administration Grant (1 PO1 HS 01053-02) and an NIH Grant (RR00012).

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